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ABBREVIATIONS

List of abbreviations

DER	Distributed Energy Resources
HES	Hybrid Energy Storage
LP	Linear Programming
MILP	Mixed-Integer Linear Programming
DR	Demand Response
CET	Central European Time
TSO	Transmission System Operator
SoC	State of Charge
AS	Ancillary Services
P2P	Peer-to-Peer

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EXECUTIVE SUMMARY

In Chapter 1, we introduced the Islander project, a European Union-supported initiative focused on the decarbonization of European islands. Task T5.3, the subject of this deliverable, centres on the development and analysis of a Daily Scheduling Service and a day-ahead optimizer for demand and generation bidding in the day-ahead market. The Daily Scheduling Service, in conjunction with the home aggregator, plays a critical role in optimizing buying and selling decisions, taking into account prosumer characteristics, appliance flexibility, and individual preferences.

Chapter 2 provided an in-depth overview of the Housing Aggregator, which integrates various energy resources such as solar panels, batteries, controllable loads (e.g., home temperature control), and electric vehicles. The system optimizes energy consumption, enables demand response, and reduces reliance on the traditional electricity grid while considering user-set comfort conditions. Active participation in the day-ahead market and ancillary services model further enhances its effectiveness.

Chapter 3 detailed the day-ahead optimizer's structure and modelling strategies. This sophisticated optimizer employs a two-stage stochastic programming approach to handle uncertainties in energy predictions, ensuring robust and reliable solutions. It effectively manages flexibility sources, such as batteries, electric vehicles, and thermostats, to align prosumers' preferences with market conditions and maximize resource utilization.

Chapter 4 presented preliminary results from simulations conducted with the day-ahead optimizer. Two experimental experiences demonstrated the system's efficiency and ability to maintain prosumer comfort while ensuring grid stability. The analysis showcased the substantial cost savings and economic benefits of implementing the day-ahead optimizer and flexible resources.

Chapter 5 offered valuable recommendations to enhance the day-ahead optimizer's performance and capabilities. These include exploring alternative solvers, incorporating compliance risk considerations, implementing a peer-to-peer market, and conducting real-world testing to validate and refine the system.

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1 INTRODUCTION

1.1 Recapitulation of the Islander Project and its relevance

The Islander project, led by the European Union, is a pioneering project aimed at achieving the decarbonisation of Borkum Island through innovative renewable energy initiatives [1]. At its core, the project focus on the strategic deployment of Distributed Energy Systems (DER) and Hybrid Energy Storage (HES) across the island. Complementing the implementation of these systems, the project entails the development of additional solutions. One such solution involves the creation of a Smart IT platform that enables remote management and monitoring of all energy assets involved. This platform will be powered by optimization and prediction algorithms, optimizing the utilization of these assets for maximum efficiency and effectiveness.

A distinguishing feature of the Islander project is its categorization of energy services based on the time of provision, both for users and the grid. This approach identifies different categories of energy assets, each tailored to operate within specific time ranges. Firstly, short-term or intra-day assets are designed to cater to energy demands within relatively short intervals, typically hours. These assets offer quick and flexible responses to fluctuating energy requirements on Borkum Island. Secondly, the project envisions assets with planned day-ahead operation. These assets address energy services that span one or more days, ensuring stable and reliable supply over extended periods. Lastly, the project considers long-term assets, intended for use over extended durations ranging from days to months, and even seasons. These long-term energy assets play a crucial role in the strategic planning and management of energy supply and demand on Borkum Island, contributing to a sustainable and resilient energy system. An exemplary instance of this is the utilization of hydrogen on the island, incorporating the optimizer developed in Deliverable D5.2.

1.2 Overview of Task 5.3: Daily Programming Service and its role in the project

Task 5.3, titled "Report on the Daily Scheduling Service," plays a pivotal role in optimizing the resources of prosumers to achieve energy efficiency and cost savings within the Islander project. The primary objective of this task is to develop and implement an aggregator and day-ahead optimizer, vital components of the intelligent energy management system. Through

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the aggregator, diverse technologies and resources available in households, such as solar panels, batteries, controllable loads, and electric vehicles, will be seamlessly integrated. This integration enables the optimization of energy consumption, the implementation of demand response strategies, and a reduction in reliance on the external power grid. The use of advanced LP mathematical optimizers will be key to maximizing the utilization of renewable energy while minimizing costs.

The fully integrated system, serving as the core of the smart platform, will act as the central control and analysis hub for all technologies employed in the Islander project. Effective communication and coordination among various components, including renewable electricity systems, batteries, controllable loads, and electric vehicles, will be facilitated through this platform. Furthermore, the platform will extend its reach across all islands involved in the project, fostering seamless collaboration and amplifying the overall impact of the innovative solutions.

2 SUMMARY OF THE DAILY SCHEDULING SERVICE

2.1 High-level description of the conceptual architecture for the scheduling service

The Daily Scheduling Service is a key component that involves interactions among prosumers, the aggregator, and the day-ahead market (Figure 1). The aggregator employs the day-ahead optimizer to make profit-oriented decisions in buying and selling energy and ancillary services, taking into account prosumer characteristics, such as physical features, appliances, and preferences.

Each prosumer within the system possesses a unique combination of appliances, like photovoltaic panels, electric vehicles (without vehicle-to-grid capability), batteries, and thermostats, which contribute to their household's energy dynamics and flexibility. Prosumers have individual preferences in using their home appliances and can establish an internal peer-to-peer market if external markets are unfavourable in terms of pricing.

The aggregator leverages available information, including market data, predictions, and weather forecasts, to make informed decisions in the day-ahead market, considering uncertainties associated with weather conditions. Bids for buying and selling energy and ancillary services are placed in the day-ahead market, allowing the aggregator to effectively

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participate in the market and meet consumers' electricity requirements.

The Daily Scheduling Service plays a crucial role in managing prosumers' appliance operations based on the energy and ancillary services awards obtained from the day-ahead market. Its objective is to effectively utilize available resources, such as photovoltaic panels, electric vehicles, batteries, and thermostats, to fulfil committed energy and ancillary services obligations. The service optimizes appliance dispatch and coordination to enhance energy efficiency, minimize costs, and ensure grid stability and reliability.

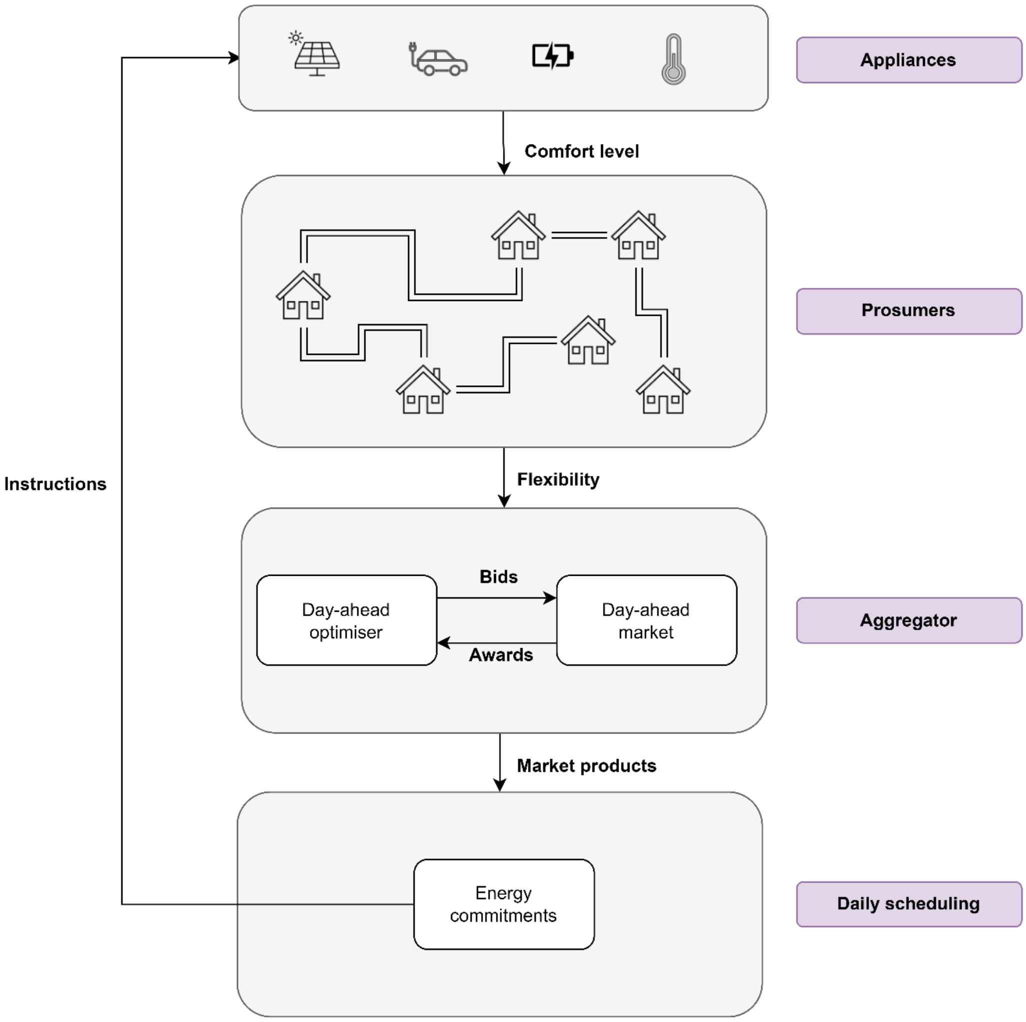

Figure 1: Conceptual architecture of the Daily Scheduling Service

2.2 Summary of sequential tasks for the day-ahead market

The framework enabling interactions between the aggregator, prosumers, day-ahead optimizer, and the Daily Scheduling Service encompasses five distinct steps:

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- Step 1 involves prosumers exchanging information with the aggregator, providing data on their inflexible loads, electric vehicle preferences, and house temperature settings. The Gridpilot platform assists in recognizing new prosumers and their appliances, considering technical and construction characteristics.
- Step 2 includes utilizing weather and price forecasts. The aggregator optimizes bids for buying and selling electricity from prosumers, taking into account the impact of weather conditions on photovoltaic system electricity production and outside temperature. These forecasts play a crucial role in determining optimal bidding strategies.
- In Step 3, the aggregator executes the optimization strategy based on information gathered earlier, considering various scenarios for energy realizations. This aims to provide profitable bids for the next 24 hours and robust solutions adaptable to different future energy realizations. (More details about the day-ahead optimizer can be found in Section 4.)
- Step 4 involves the clearing of the day-ahead market, declaring awards from submitted bids. Energy and ancillary services awards are determined for each hour of the upcoming day. The strategy of submitting demand bids with the market price-cap and non-priced generation bids helps ensure alignment between bids and awards.
- In Step 5, the Daily Scheduling Service receives awards from the day-ahead market. It then disaggregates the awards and assigns schedules to individual prosumers' appliances. Prosumers' appliances can be controlled either telemetrically or manually, depending on their specific characteristics. (Further control mechanisms details can be found in Deliverable 5.1.)

This five-step framework facilitates the seamless flow of information, bid optimization, market clearing, and scheduling of prosumer appliances, ensuring efficient and reliable energy management within the system.

2.3 General outline of disaggregation and settlements process

After the day-ahead optimizer submits the bids to the market based on the aggregated features of prosumers, the Daily Scheduling Service plays a crucial role in receiving the awards from the market and distributing the commitments to each individual prosumer. The desegregated commitments are allocated to prosumers in proportion to their respective bids submitted during the day-ahead market.

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To illustrate this process, let's consider a specific scenario. Suppose the aggregator has successfully sold a total of 1 kWh of electricity at a price of $20/kWh for a specific hour. Additionally, assume that there are two prosumers in the system, with one prosumer having a bid availability of 0.7 kWh and the other prosumer having a bid availability of 0.3 kWh for that same hour.

In line with maintaining the proportionality of the bids, the commitments and settlements are also allocated accordingly. In this example, the aggregator's profit for that hour is $20. Based on the proportion of their bids, the first prosumer, with a bid availability of 0.7 kWh, will receive a settlement of $14 (0.7 kWh * $20/kWh), while the second prosumer, with a bid availability of 0.3 kWh, will receive a settlement of $6 (0.3 kWh * $20/kWh).

This proportional distribution system will allow the costs or benefits generated in the aggregator to be allocated appropriately. In this way, those buildings that consume more energy will contribute more to the cost, while those with less demand will bear a proportionately smaller burden. This achieves a fair and equitable distribution of resources and encourages responsible and efficient use of energy within the building aggregator.

3 DAY-AHEAD OPTIMISER

3.1 Summary of the day-ahead optimiser's purpose and role in the project

The core concept of the Day-ahead optimiser is to achieve efficient energy management using an aggregator that leverages prosumers' flexibility and data from forecasts. This optimisation occurs just before the German day-ahead market closes, aiming to maximize benefits and minimize costs of participation. The optimiser intelligently adjusts energy consumption and generation parameters for each building within the aggregator's portfolio. It employs linear programming (LP) to determine optimal bidding values for both energy and ancillary services in the day-ahead market.

Flexibility plays a crucial role in this optimization process. Prosumers can tap into various flexibility sources, allowing the Daily Programming Service to adjust their energy generation and consumption based on the day-ahead optimiser's strategy. Photovoltaic systems and batteries (discharging) facilitate generation flexibility, while thermostats, electric vehicles, and batteries (charging) enable load flexibility. The optimiser incorporates these flexibility sources,

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aligning prosumers' preferences with market conditions to ensure efficient resource utilization and meeting individual prosumers' objectives.

This customization empowers prosumers to align their energy patterns with personal preferences and requirements. The Day-Ahead Optimizer takes these preferences into account when devising the bidding strategy for each prosumer, considering their individual needs and objectives.

3.2 Brief overview of modelling strategies used in the optimisation process

The day-ahead market bidding strategy involves a complex optimization problem that considers various factors such as electricity price predictions, market participant bids, price-maker influence, weather conditions, and electricity demand forecasts. Due to the inherent uncertainties in these predictions, decision-makers, including aggregators, must protect themselves while aiming to maximize profits. To address this challenge, a two-stage stochastic programming strategy was implemented for the day-ahead optimizer.

In the "here and now" stage, decisions are made based on available information at the time of the day-ahead market. The "wait and see" stage involves making real-time decisions after the uncertainties have been realized. This two-stage approach accounts for a range of scenarios representing different realizations of uncertainties, capturing potential variations in electricity prices, demand, and other factors.

To manage computational complexity, the day-ahead optimizer avoids using binary variables. Instead of a mixed-integer linear programming (MILP) formulation, a linear programming (LP) formulation was adopted. The LP formulation cleverly addresses charging and discharging constraints without the need for binary variables. The objective function is designed to ensure charging and discharging operations have a negative impact on the objective function value when minimizing or a positive impact when maximizing.

The day-ahead optimizer consists of one objective function and constraints related to market trading, energy balance, and each appliance considered in the Daily Programming Services.

- Objective function

The objective function of the Daily Programming Services is designed to optimize performance and incorporates five distinct terms:

1. Energy Market Bids: This term reflects the net cost of buying and selling energy at

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forecasted prices, with positive values representing demand bids and negative values indicating supply bids.

2. Ancillary Services Bids: Capturing revenue from selling secondary reserve capacity in the day-ahead market, this term involves making adjustments in generation or consumption levels based on system requirements.

3. Imbalance Cost: Quantifying the expected deviation between planned energy commitments and real-time realizations, this term indicates a shortfall or excess of energy compared to the commitments made.

4. AS Deployment: Accounting for the deployment of ancillary services, specifically the secondary reserve, in both upward and downward directions, this term incurs payments from the grid operator to the aggregator or vice versa.

5. AS Not Supplied: This term captures the discrepancy between the committed and actual provision of ancillary services in both upward and downward directions. Minimizing this term is crucial to avoid financial penalties for non-compliance with capacity obligations.

The problem constraints in the optimization process include the following:

• Market trading and energy balance constraints: These constraints compare day-ahead market commitments to actual energy realizations, capturing deviations between committed and delivered energy, as well as discrepancies in reserve capacity.

• Electric vehicles (EV) constraints: These constraints consider factors like charging capacity, unavailability, state of charge (SOC) progression, departure SOC, SOC at arrival, SOC limits, and deployment of reserve services, optimizing EV charging strategies while meeting ancillary service requirements.

• Battery constraints: These constraints provide flexibility in energy generation and demand, ensuring batteries contribute to secondary reserve services while maintaining SOC within predefined limits.

• Photovoltaic generation constraints: These constraints optimize PV generation output, considering available electricity and curtailment amounts, and allow PV systems to adjust their output for secondary reserve deployment.

• Thermostats constraints: Thermostats adjust electricity demand based on temperature preferences, fulfilling secondary reserve obligations while maintaining prosumer comfort and grid stability.

These constraints play a crucial role in the optimization process, ensuring efficient utilization of resources while meeting ancillary service obligations and maintaining overall system performance.

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4 PRELIMINARY RESULTS

In the preliminary results, the day-ahead optimiser was subjected to a series of simulations to evaluate its stability and convergence capabilities in generating optimal and robust solutions. The software's performance was influenced by factors such as the number of prosumers, their associated appliances, the number of scenarios for inflexible loads, and photovoltaic generation. Additionally, multiple days ahead were considered to assess the profitability of day-ahead market operations, impacting the software's performance.

This section presented two experimental experiences. Case 1 involved 5 prosumers, 3 scenarios, and a 1-day planning horizon, focusing on computational burden, final solution, and appliance operation. On the other hand, Case 2 encompassed 5 prosumers, 10 scenarios, and a 7-day planning horizon, examining the day-ahead optimiser's performance over an extended planning horizon and across different days. The simulations were executed on a local computer with specific hardware specifications. The results and performance characteristics derived from these simulations offer valuable insights into the day-ahead optimiser's potential for practical implementation in real-world energy markets.

4.1 Summary of experimental experiences and their outcomes

In the first experimental experience, the day-ahead optimizer demonstrated its ability to provide effective solutions for energy bids, accurately distinguishing between supply bids (negative values) and demand bids (positive values). The optimizer efficiently managed battery operations, avoiding simultaneous charging and discharging for all prosumers, which significantly reduced computational effort.

Throughout the planning horizon, the optimizer successfully controlled the state of charge (SoC) trajectory of prosumers' batteries within the prescribed upper and lower limits, ensuring optimal utilization and safety. The SoC behaviour of prosumers' electric vehicles (EVs) also proved effective, providing sufficient energy for their travel requirements, with the SoC gradually decreasing during travel until reaching the arrival time for recharging.

A significant outcome was the consistent maintenance of prosumers' home temperatures within their preferred range, showcasing the optimizer's ability to meet prosumers' comfort preferences while ensuring grid stability. These results highlight the day-ahead optimizer's excellent performance in efficiently managing energy resources, addressing prosumers'

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preferences, and contributing to grid stability.

In the second experimental experience, the day-ahead optimizer was evaluated with 5 prosumers, 10 scenarios, and a 7-day planning horizon. The optimization process took approximately 1.5 hours and utilized around 292 MB of memory. The optimizer successfully obtained solutions for energy and ancillary services bids for the next 7 days, extending the planning horizon beyond the typical 24-hour limit of the day-ahead market.

Similar to the first case, the optimizer effectively managed the operation of prosumers' batteries, ensuring exclusive charging or discharging modes for all batteries. The state of charge (SoC) variations of prosumers' batteries was successfully controlled within the specified upper and lower limits throughout the planning horizon. Regarding prosumers' electric vehicles (EVs), the optimizer efficiently adjusted the SoC during travel and ensured stable charging upon reaching the arrival time.

Lastly, the optimizer maintained consistent temperature control in prosumer households, ensuring temperatures remained within the specified comfort range of 17 to 23 degrees. Overall, the second experimental experience demonstrated the day-ahead optimizer's capability to effectively manage energy resources, optimize bids, and meet prosumers' preferences over an extended planning horizon.

4.2 High-level insights from the economic analysis conducted in D5.3

In this section, we conducted an economic analysis on settlements and the impact of the aggregator's role, as well as the flexible resources (as battery and solar PV). It is important to note that the analysis is based on synthetic data and may not reflect real data from the project. However, the results indicate promising potential in terms of cost savings.

In the first case with 5 prosumers and 3 scenarios over 1 day, the day-ahead settlements for the aggregator's operations amounted to -4.11 $. This cost is distributed among prosumers based on their shares in electricity consumption and generation throughout the day.

When the battery, solar PV, and the aggregator's role in optimizing bids are not considered, prosumers return to being passive consumers. In this scenario, the aggregated average electricity demand for the operating day is approximately 163 kWh, resulting in a billing of -8.18 $. This comparison clearly shows that the operation with flexible resources and the aggregator leads to nearly 50% in savings.

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While the savings may seem modest for a small number of prosumers and a single day, it is crucial to consider the potential over time. The annual savings for this case amount to approximately 1400 $ if the behavior remains consistent throughout the year, or 35000 $ over the lifetime of batteries and solar PV (around 25 years). As the number of prosumers and flexible appliances increases, these savings are expected to significantly grow.

5 CONCLUSIONS

The conclusions presented in this deliverable focus on Task 5.3 - Daily Scheduling Service, which developed and analysed a day-ahead optimizer for demand and generation bidding in the day-ahead market. The Daily Scheduling Service, involving interactions between prosumers, the aggregator, and the day-ahead market, plays a vital role in optimizing buying and selling decisions based on prosumer characteristics, appliance flexibility, and individual preferences.

Through experimental experiences in two cases, the day-ahead optimizer's performance was evaluated. Case 1, with 5 prosumers, 3 scenarios, and a 1-day planning horizon, assessed the optimizer's short-term performance, computational burden, final solution, and appliance operation. Case 2, with 5 prosumers, 10 scenarios, and a 7-day planning horizon, explored the optimizer's capabilities over a longer timeframe and transitions between days, along with prosumers' appliance performance.

The results highlighted the crucial role of the aggregator and resource flexibility in achieving cost savings. Consideration of batteries, solar PV, and the aggregator's bid optimization led to nearly 50% savings in the aggregated average electricity demand for a single day, shifting prosumers from passive consumers to active participants. Projecting these savings over time demonstrated substantial economic benefits, making the approach economically advantageous over an annual or lifetime perspective.

It's important to note that the analysis was based on synthetic data, and real-world results may vary. Nevertheless, the findings indicate a promising direction for the project. The combination of the day-ahead optimizer, aggregator functionalities, and flexible resource utilization allows prosumers to align their energy consumption and generation with preferences, achieve cost savings, and enhance energy efficiency.

The conclusions highlight the significance of the Daily Scheduling Service and the day-ahead optimizer in facilitating efficient bidding, resource utilization, and economic benefits for

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prosumers. These findings provide a foundation for further refinement, expansion, and real-world implementation of the framework, leading to a more sustainable and economically viable energy system.

6 RECOMMENDATIONS FOR TASK 5.3

As we conclude the analysis and evaluation of the day-ahead optimizer in Task 5.3, several key recommendations emerge to further enhance its performance and capabilities. These recommendations encompass various areas of improvement:

- Improve Solver Performance: The simulations revealed that the current *glpk* solver exhibited weak performance and sometimes failed to provide optimal solutions. To address this limitation, a comprehensive analysis of alternative solvers should be undertaken. Exploring more efficient and accurate solvers will significantly improve the overall performance of the day-ahead optimizer.
- Consider Compliance Risk: In the next version of the day-ahead optimizer and the forthcoming real-time optimizer, it is crucial to incorporate considerations for compliance risk. Implementing a risk slider within a Conditional Value at Risk (CVaR) framework would prioritize ancillary services' compliance, minimizing regulatory penalties and additional fees for the aggregator. By proactively managing compliance risks, the optimizer can enhance system reliability and financial viability.
- Implement Peer-to-Peer Market: Introducing a peer-to-peer market feature within the day-ahead optimizer holds substantial potential. This addition would enable direct transactions between prosumers within the aggregator area, fostering more efficient energy exchange and nurturing a decentralized energy ecosystem. Integrating a peer-to-peer market empowers prosumers to interact and optimize their energy consumption and generation at a localized level, promoting energy self-sufficiency and community resilience.
- Conduct Real-World Testing: To validate the performance and feasibility of the developed day-ahead optimizer, real-world testing and implementation should be pursued. Real-world testing provides valuable insights into the optimizer's practical performance, identifies potential challenges, and allows for system refinement based on practical feedback. This testing approach will also assess scalability, reliability, and the overall impact of the optimizer within the broader energy market context.

By addressing these recommendations, the day-ahead optimizer can be further enhanced,

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providing more robust and effective solutions for demand and generation bidding in the day-ahead market. The implementation of these improvements will contribute to a more efficient, reliable, and economically advantageous energy management system for prosumers and the broader energy market.

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